Sediment Transport Modeling in the New York Bight

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LONG-TERM GOALS

The long-term goal of the Rutgers University Coastal Ocean Modeling and Observation Program (COMOP) is the construction of a real-time multi-platform adaptive sampling network and an integrated data-assimilative coupled modeling system for the New York Bight (NYB).

OBJECTIVES

This ONR grant focuses on the development of a coupled shelf circulation/bottom boundary layer model to study storm-driven coastal sediment transport. Specific issues to be investigated include the relative roles of waves, currents, tides and realistic topography.

APPROACH

COMOP sediment transport studies are funded by NOAA/NURP (observations) and ONR (modeling). Observational datasets collected at the Rutgers Long-term Ecosystem Observatory (LEO-15) and in the Gulf of Mexico provide model formulation and validation data. Our modeling strategy involves coupling a bottom boundary layer model to a shelf circulation model to examine three-dimensional patterns of sediment transport. This approach consists of three related efforts:

- exploratory studies with a coupled version of an existing shelf circulation model (Princeton Ocean Model, POM) and an existing Bottom Boundary Layer Model (BBLM) (Glenn and Grant, 1987);
- development of a next generation BBLM based on the LEO-15 data;
- development of a new shelf circulation model (S-Coordinate Rutgers University Model (SCRUM)) and coupling to the new BBLM.

WORK COMPLETED

(1) Coupled POM/BBLM

Working with Dr. Tim Keen from the Naval Research Laboratory-Stennis, the modified Glenn and Grant (1987) BBLM (Keen and Glenn, 1994) was coupled to the POM and used

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to study currents and sediment transport in the Gulf of Mexico during Hurricane Andrew. Spatially distributed observations from the LATEX experiment were used to develop several quantitative measures of current hindcast skill (Keen and Glenn, 1996). These skill scores were used to examine model sensitivities to vertical and horizontal grid resolution, domain size, surface and bottom stress formulations, thermocline mixing, wave breaking, and initial conditions (Keen and Glenn, in press). The best model configuration was used to examine the spatial/temporal variability of the hurricane-driven coastal current fields (Keen and Glenn, submitted-a), bottom boundary layer parameters (Keen and Glenn, submitted-b), and sediment transport patterns (Keen and Glenn, submitted-c).

(2) New BBLM
A new BBLM has been constructed with the additional support of Richard Styles' AASERT fellowship. Improvements over Glenn and Grant (1987) include:

- a continuous eddy viscosity across the top of the wave boundary layer,
- inclusion of sediment induced self-stratification within the wave boundary layer,
- testing and development of alternative bottom roughness and reference concentration models, and
- improved numerical solutions for a depth-limited bottom Ekman layer with stratification.

The near bottom, constant stress layer version of the BBLM model was first presented at the 8th International Conference on Physics of Estuaries and Coastal Seas in The Hague (Styles and Glenn, submitted). Validation data has been acquired through an ongoing 5-year, NOAA/NURP funded, multi-institutional study of storm-driven sediment transport and bottom boundary layer dynamics at LEO-15. Observations include full water column current profiles from an ADCP, BASS and a LDV, sediment concentrations from ABSS and LISSTs, and bottom roughness from a Sector Scanning Sonar. Model/data comparisons have been used to examine model sensitivities and set model parameters for the LEO-15 region. Richard Styles' thesis defense on this topic is scheduled for December, 1997.

(3) SCRUM
Three-dimensional circulation modeling work has focussed on the testing and documentation of version 3.0 of the S-Coordinate Rutgers University ocean Model (SCRUM). The new version of SCRUM has been completely rewritten and structured in a more modular form to facilitate future developments - e.g., inclusion of assimilation, bio-optical, and sea ice dynamics. There are now several options for horizontal mixing of momentum and tracers along S-coordinate levels, geopotential (constant depth) surfaces, or epineutral (constant density) surfaces. An additional option for the horizontal and vertical advection of tracers was incorporated based on the positive definite algorithm proposed by Smolarkiewicz (1983). Alternate parameterizations of surface mixing include the models of Pacanowski and Philander (1981), Mellor and Yamada (1974) levels 2 and 2.5, and Large et al. (1994). The bottom boundary layer model is that proposed by Styles and Glenn (submitted). The input and output fields to SCRUM are handled via NetCDF data management software. There are

both serial and parallel versions of SCRUM. SCRUM version 3.0, including pre- and post-processing software, and complete documentation are available via the WWW. In addition to its central role in the modeling activities within COMOP, SCRUM v3.0 has recently been adopted for application to studies on the U.S. West Coast (McWilliams, Moisan, Miller, Powell), and the Coastal Gulf Of Alaska and the Southeast Bering Sea (Hermann, Stabeno).

RESULTS

(1) Coupled POM/BBLM
Model/data comparisons during Hurricane Andrew indicate that model performance is most dependent on the parameters within the turbulent closure scheme and the initial density distribution. The best overall model performance is found by adjusting the closure scheme coefficient that decreases turbulence dissipation and thereby increases turbulent mixing in stratified regions. Results incorporating mixing due to wave breaking and a depth-dependent initial density field also produce reasonable results, with differences between the skill scores insufficient to determine which approach is better.

The best Hurricane Andrew hindcast was used to study current, boundary layer parameters and sediment transport patterns. Surface currents mimic the wind pattern until the eye approaches shallow water, producing a large storm surge on the eastern side. The strongest bottom currents are experienced early during downwelling favorable wind conditions. An offshore jet develops to the right of the storm track as the eye moves landward, with weaker upwelling favorable currents experienced following landfall. Bottom roughness is dominated by near bed sediment transport in the stronger flows as the storm approaches and by large ripples after landfall. Suspended sediment transport is greatest during the peak flows as the storm approaches, with spatial patterns consisting of westward transport over a broad area to the right of the storm track and a rapid decline to the left. The thickest storm beds develop along the left side of the storm track due to the advection of sediment initially and primarily from the east and later in smaller amounts from the west.

(2) New BBLM
The new full water column suspended sediment induced stability parameter is no longer required to peak at the top of the wave boundary layer, resulting in a much wider range of predicted suspended sediment profiles with a significant dependence on the near bed eddy viscosity profile and the number of sediment size classes. Matching predicted sediment concentration profiles to observations, however, generates new BBLM parameters that produce sediment transport rates comparable to the old BBLM. The directional dependence of bottom roughness similar to existing empirical formulations appears adequate when waves and currents are of similar magnitude, but a directionally independent bottom roughness model appears to be more appropriate for strong waves and weak currents. The sediment reference concentration constant (γ_0) still appears to be of order 10^{-3}, again similar to the previous BBLM.

(3) SCRUM
Upon completion of testing, we began development of a real-time coastal modeling system for the New York Bight that includes the LEO-15 research site. Preliminary results emphasize the important role of the bottom topography in recreating the recurrent upwelling

centers discussed in Glenn et al.'s (1996) observations and idealized numerical experiments. Currently we are exploring and examining physical and numerical parameters and several open boundary condition options to establish the basic coastal circulation in the New York Bight that will be the basis for sediment transport and data assimilation experiments.

IMPACT/APPLICATIONS

A coupled shelf circulation/bottom boundary layer model has been tested against the most extensive shallow water hurricane dataset available, with sensitivities to turbulent closure and initial conditions being identified as the most critical. Shelf sedimentation patterns are highly dependent on advection, supporting the need for the coupled model approach used here.

The Glenn and Grant (1987) BBLM is in widespread use throughout the sediment transport community. The Styles and Glenn BBLM will include many of the theoretical advances made possible through improvements in bottom boundary layer instrumentation over the last 10 years. The new model has been thoroughly tested with data from LEO-15 and preliminary versions have already been coupled to the SCRUM shelf circulation model. LEO-15 data comparisons indicate that although the details may vary, the sediment transport rates predicted by the new BBLM are often similar to those predicted by the old BBLM, increasing our confidence in the above Hurricane Andrew results.

Significant effort was invested on the testing of SCRUM 3.0 to insure dynamical, numerical, and robust performance across a wide range of test examples including idealized coastal, basin-scale, and GFD ocean circulation problems. After several months of testing, a beta-release version was offered to the ocean modeling community in July, 1996. This makes SCRUM v3.0 the most systematically tested of our family of models before a release. The new version of SCRUM is now being used by several colleagues worldwide.

TRANSITIONS ACCOMPLISHED AND EXPECTED

The coupled model is now being used by Dr. Keen at NRL-Stennis for Navy applications in other regions. The new BBLM will soon be made available to the scientific community via ftp. USGS has proposed to continue support of the coupling of the new BBLM to the latest version of SCRUM and its application to sediment transport in the New York Bight.

We expect that a data-assimilative, SCRUM shelf circulation model with coupled surface and bottom boundary layers eventually will be transitioned to operational status in some coastal region of Navy interest. SCRUM is being used by researchers worldwide in applications ranging from the basin scale to coupled atmosphere/lake models to coupled ocean/ice models.

RELATIONSHIPS TO OTHER PROJECTS FOR ONR OR OTHER AGENCIES

COMOP was initiated in 1993 by oceanographers at the Rutgers University Institute of Marine and Coastal Sciences (IMCS) working with engineers from the Ocean Systems Laboratory of the Woods Hole Oceanographic Institution. COMOP is supported by grants from ONR, NSF, NOAA/NURP and the State of New Jersey.

This ONR project provided the initial support that produced the validated version of the S-Coordinate Rutgers University Model that is now available via ftp. The SCRUM model is one of two models being used by the Rutgers group for North Atlantic Basin scale modeling in DAMEE. New Rutgers research projects made possible through this modeling effort include the recently awarded ONR sponsored COMOP: Real-Time Adaptive Sampling Networks and the NOPP sponsored Multi-scale Model-Driven Sampling with Autonomous Systems at a National Littoral Laboratory.

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